

PROBING BOUNDARY LUBRICATION PHENOMENA ON TEXTILE RELEVANT SURFACES VIA LFM

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Introduction

Boundary lubrication is one of fundamental phenomena in textile processing. Study of boundary lubrication provides insight into interactions between lubricants and fibers. Its importance has been overlooked in textiles due the lack of analytical techniques capable of probing friction phenomena with nanoscale resolution. [1, 2]

In our work, we studied three kinds of polymers --- polyethylene (PE), polypropylene (PP), and cellulose, commonly manufactured into textiles. To investigate the impact of different surface chemistry on boundary lubrication, we applied a model lubricant, Pluronic®, on polymer coated surfaces. The correlation between surface chemistry and friction phenomena was explored to obtain a guide for designing effective lubricants for textile processing. Improvements in the efficiency and productivity of fiber generation and textile processes are critical to create a sustainable textile industry.

Experimental

Preparation of PP, PE, and cellulose coated surfaces

The PP, PE, and cellulose thin films were prepared via spin-coator (WS-400A-6NPP, Laurell Technologies), employing the method reported by Song et al. [3]

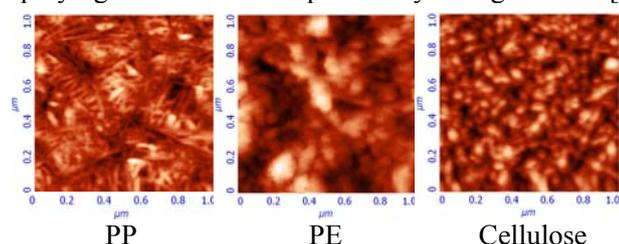


Figure 1. 1- μm AFM topographical images of cellulose, PE, and PP thin films spin-coated on silica wafers (images obtained in air).

The triblock copolymer, $\text{EO}_{19}\text{PO}_{29}\text{EO}_{19}$ (BASF), was applied as a lubricant on the PP, PE, and cellulose coated surfaces.

Lateral Force Microscopy

Lateral force microscopy (TEGRA Prima, NT-MDT) was employed to probe friction properties of the model polymer surfaces. Measurements were conducted in air (air-test), in DI water (water-test), and a 1% by weight lubricant solution (lubricant-test). Before imaging, each surface was cleaned with DI water and 95% ethanol and dried with compressed air. A MikroMasch contact mode probe with a force constant of 0.35N/m was used. In both immersion tests (water-test and lubricant-test), the respective solution was injected into a liquid metal cell in which the wafer samples were positioned. All of the tests were performed with a scan frequency of 1 Hz and a scan size of 1 μm .

Results and Discussion

PP surface

PP surfaces were probed via LFM in air, water, and lubricant solutions. The PPO block of the tri-block copolymer had a higher affinity towards the PP surface than the PEO block. A buoy-anchor-buoy (B-A-B) arrangement of the tri-block copolymers in relation to the PP surface was proposed as shown in Figure 2. The anchoring PPO block tightly bounds on the PP surface resulting in a low mobility of the PPO block. The PPO block behaved as an inner well-packed layer, protecting the surface against abrasion. Meanwhile, two PEO blocks behaved as an outer canopy layer with high, liquid-like mobility and low shear resistance, serving as an effective lubricant. The PEO blocks were hydrophilic and floated away from the surface as tails. Similar self-assembled structures of the same tri-block copolymer were reported on hydrophobic non-polymeric surfaces.

When the external force increased to a critical point of approximately 27.8nN, the friction coefficients rapidly increased to similar to those measured in air (Figure 2). This is most likely because the critical force caused a dramatic change in the molecular structure of the lubricant layers. The critical force most likely damages the self-assembled layers, destroying the organization in

their structures and preventing them from functioning as an effective lubricant. [4]

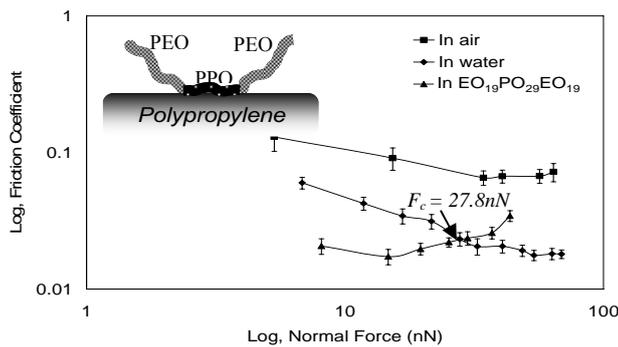


Figure 2. The proposed buoy-anchor-buoy structure and logarithmic relationship of friction coefficient and normal force on polypropylene surfaces.

PE surface

Figure 3 illustrates the friction coefficients curves against the normal force in the corresponding environments. Scratch and plowing was shown in the surface morphology when the PE surface was imaged in air. These marks disappeared after water was added, and a clearer morphology was obtained under the presence of lubricants in solution. Based on the finding that the PPO block in the tri-block copolymers had higher affinity towards the PE surfaces, it was proposed that a similar B-A-B structure is formed on the PE surface shown in Figure 3. A large stretching force occurred to the PEO blocks, extending them away from the PE surface. The outer PEO layer was more flexible on the PE surface than on the PP surface. The critical normal force was found to be 51.7 nN. After the critical force, the self-assembled structure breaks down decreasing lubrication performance.

Cellulose surface

The friction coefficient curves indicated that water reduced the friction coefficients similar to the phenomenon observed on PP and PE surfaces (Figure 4). The addition of lubricant, however, the friction coefficients with lubricants were higher than those measured in water alone. The critical normal force was 8.6 nN. It was lower than those for PP and PE surfaces. In contrast to the PP and PE surfaces, the PEO block had a higher affinity towards cellulose than the PPO block. A reversed structure, anchor-buoy-anchor (A-B-A), was proposed for the cellulose surface shown in Figure 4. The PEO blocks anchored on the hydrophilic cellulose surface and the PPO block was repelled from the surface. [5] The PPO buoy block had poor mobility because it was constricted by the two anchored PEO blocks. The A-B-A structure of the copolymer layers could not produce an efficient lubrication. As for the cellulose surfaces, a low critical force was detected at 8.6 nN, indicating a weak binding between the PEO and cellulose surfaces.

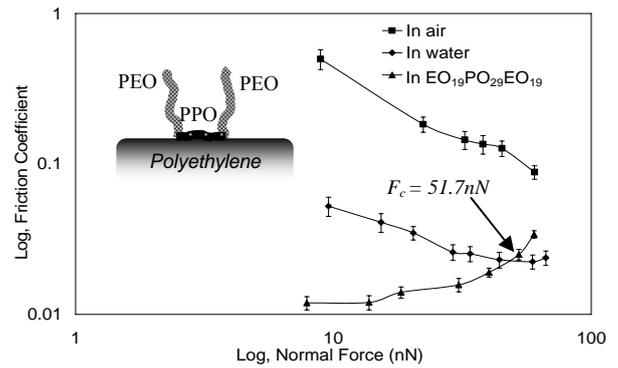


Figure 3. The proposed buoy-anchor-buoy structure and logarithmic relationship of friction coefficient and normal force on polyethylene surfaces.

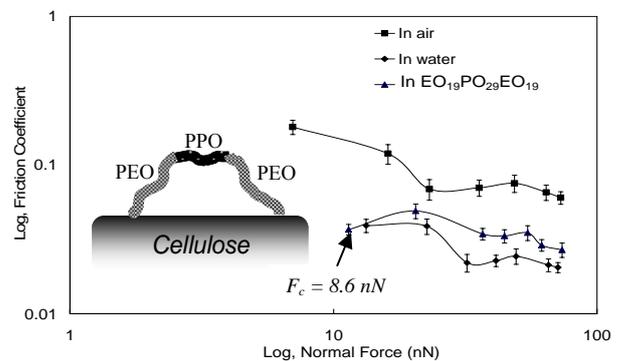


Figure 4. The proposed anchor-buoy-anchor structure and logarithmic relationship of friction coefficient and normal force on cellulose surfaces.

Conclusion

The PEO-PPO-PEO tri-block copolymers have been recognized to form unique molecular structures on polymer coated surfaces. The conformations and behavior of these molecular structures are essential to the function of lubricants as these molecular structures influence the friction and wear behavior of materials. Correlating their lubrication properties with molecular self-assembled structures allows the intelligent design of efficient textile lubricants.

References

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